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Energetic Electron Measurements from the Galileo Jupiter Probe

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Abstract

Energetic trapped electrons were measured with the Galileo Jupiter Probe, with samples from inside Io's orbit, down to just above the atmosphere. The energetic electron fluxes and spectra agree well with the earlier results from the Pioneer spacecraft, where comparison may be made under the assumption of simple power law spectra. New features from the Galileo measurements include direct observations of the electron pitch angle distributions and spectral softening, both as the atmosphere is approached and at smaller pitch angles at each measurement location.

Introduction

On December 7, 1995, the Galileo Probe successfully returned in situ atmospheric data from Jupiter. Prior to atmospheric entry, beginning inside the orbit of Io, magnetospheric energetic particle fluxes were measured using a shielded, two-element solid state detector telescope that viewed through the aft heat shield of the Probe [Fischer et al., 1992]. Analyses of energetic electron fluxes and spectra are reported here; proton fluxes and spectra were also measured [Fischer et al., 1996].

Probe Trajectory

In figure 1 the Galileo Probe trajectory in magnetic coordinates is shown superposed on Van Allen's [1976] Pioneer contours of energetic electron count rates. This figure is for illustrative purposes only, since the Pioneer results from December 1973 and December 1974 were organized using a tilted dipole magnetic coordinate system, whereas the Probe trajectory is given using a magnetic coordinate system based on O6 multipole coefficients [Connerney, 1993]. Also, the results reported subsequently here use the even newer VIP4 multipole magnetic coordinate system [Connerney et al., 1998]. The difference in the plot of the Probe trajectory when using the two magnetic multipole systems is relatively small, except within 0.4 Jupiter radii from the planet's surface. This figure indicates that peak flux regions near the magnetic equator were avoided by the Galileo Probe.

Results

Directional energetic electron fluxes were deduced from spin-sectored, corrected counting rates above two energy thresholds. A more heavily shielded, coincidence channel provided a measurement with higher mean energy; a less heavily shielded, non-coincidence channel provided a lower energy threshold [Fischer et al., 1992]. Directional ion contributions and rates due to particles penetrating the side of the telescope were estimated using various assumptions, or determined from data, and subtracted. Rates due to particles penetrating the sides could be determined knowing rates in the inner, more heavily shielded telescope element due to directional particles; those rates were known in turn from the telescope coincidence rates. The responses of the two channels to energetic electron fluxes exterior to the Probe heat shield were determined with Monte Carlo simulation calculations. The energy and angular dependence of sensitivities to electrons from the direction of the entrance aperture were principally determined using the ITS code [Halbleib, 1988]. Omnidirectional responses to a suite of particles using the CERN GEANT code were also determined; calibrations using a 30 MeV linear accelerator at LLNL were done as well [Fischer et al., 1992]. The relative responses of the two channels to power law electron energy spectra were determined from the simulations and matched with electron count rate ratios deduced from the data from Jupiter to obtain power law exponents. Directional fluxes were then calculated using these power laws. The directional fluxes were integrated over the ranges of pitch angles observed, deduced from the VIP4 magnetic field model, to obtain omnidirectional fluxes. In figure 2 these omnidirectional fluxes, calculated for an electron energy threshold of 21 MeV, are compared with those given in figure 1, from the Pioneer spacecraft. These fluxes deduced from the Galileo measurements appear to agree well with the earlier results; they run somewhat lower in magnitude, but not unreasonably so considering their uncertainties, and they appear to peak at a higher altitude. These Galileo omnidirectional electron fluxes may be accurate to within

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a factor of 2. An important uncertainty is the effective solid angle of sensitivity, affected by electron scattering in the Probe aft heat shield, and determined from Monte Carlo simulations for individual energies and directions. The effective areas of the solid state detectors are affected by detection sensitivity at the edges of the detectors. Effects of digitization of the experiment's register values are negligible, as are counting statistics, except for the data sample closest to Jupiter's atmosphere. The decrease in flux shown in figure 2 as Jupiter's atmosphere is approached could not have been measured previously. The figure omits results from a number of additional measurement locations at which only spin-averaged, not spin-sectored, electron data were acquired.

In figure 3 integral electron power law exponents deduced from the Galileo Probe data are given. A spectral softening with decreasing pitch angle is observed at all locations; this is discussed further below. The spectral forms for locally mirroring electrons appear slightly harder than those reported [Van Allen, 1976] from the Pioneer results for omnidirectional fluxes at similar locations. The gradual spectral softening as Jupiter's atmosphere is approached may also be seen in the results of calculations of equatorial diffusion of Jupiter's trapped energetic electrons [de Pater and Goertz, 1990]. Just above the atmosphere the electron spectra soften much more noticeably; energy loss in the atmosphere may result in steeper, soft spectra.

In figure 4 electron pitch angle distributions and the behavior of the spectral softening observed at smaller pitch angles are given for three locations. The pitch angle distributions were obtained using directional fluxes calculated for energies above 21 MeV and assuming a $\sin^n$ dependence on pitch angle. A least-squares fit to spin-sectored data was used to obtain both an orientation for the local magnetic field and a value for the exponent n. The field orientations obtained with this procedure differ from those calculated using the O6 or VIP4 models, but they tend to organize the spin-sectored data in a physically meaningful way. The electron pitch angle distribution for the most distant data shown does not follow closely a power law, having excess flux apparently at the minimum pitch angle sampled, as well as locally mirroring. The pitch angle distributions closer to the planet are fit better with power laws. The pitch angle distributions become narrower, closer to the planet, where the loss cone is wider (see also Fischer et al. [1996]). The spectral softening at smaller pitch angles appears both to match a linear fit better and to be a steeper function as the planet is approached. A deconvolution of the experiment's angular response was not performed when the above results were deduced.

Conclusions

Electron flux measurements from the Galileo Jupiter Probe have provided a good sample from Jupiter's inner magnetosphere. The fluxes and spectra agree reasonably well with earlier results obtained with the Pioneer spacecraft where comparison may be attempted. A number of new features have been found; these include a direct observation of the decrease in flux and spectral softening as the atmosphere is approached, direct measurements of pitch angle distributions, and persistent spectral softening at smaller pitch angles.

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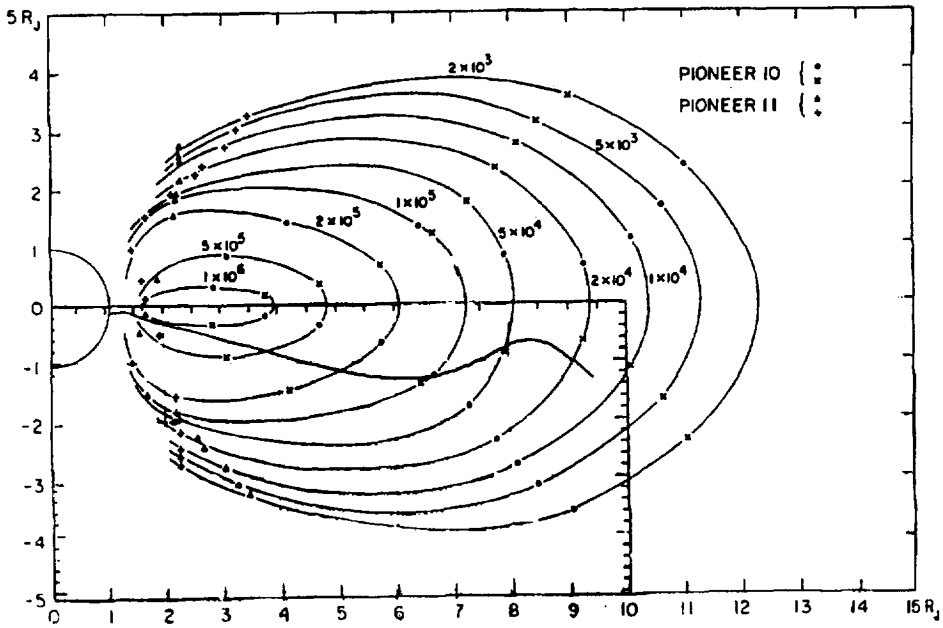

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Figure 1. Illustration of Galileo Probe trajectory, in magnetic coordinates, superposed on energetic electron count rate contours (s^{-1}) obtained from Pioneer 10 and 11 measurements [Van Allen, 1976]. The Probe trajectory was calculated using the O6 magnetic coordinate system [Connemey, 1993], whereas the count rate contours were drawn using coordinates from a centered, tilted magnetic dipole.

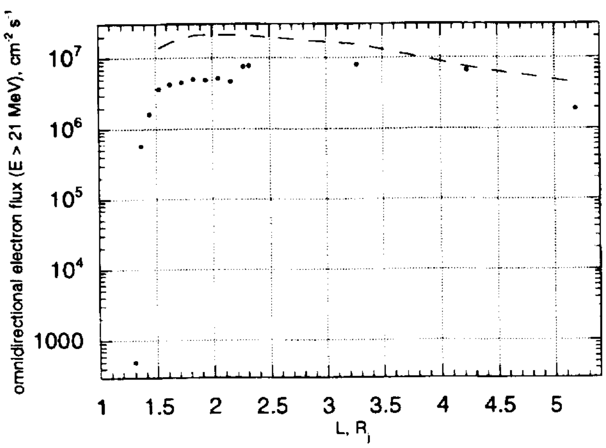

Figure 2. Omnidirectional electron fluxes above a 21 MeV energy threshold, deduced from Galileo Probe measurements, assuming power law energy distributions. A comparison with earlier Pioneer results is given by the dashed line which was obtained from figure 1. The magnetic shell parameter values (L) along the abscissa were obtained using the VIP4 model for Jupiter's magnetic field [Connerney et al., 1998].

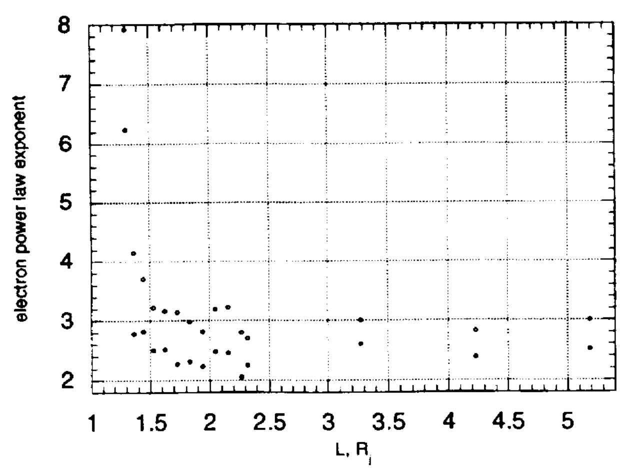

Figure 3. Values of power law exponents for energetic electrons, from Galileo Probe measurements. The solid symbols are for locally mirroring electrons, and the hollow symbols for the minimum pitch angle observed at each location. At each location, the spectra are softer for the smaller pitch angles. The abscissa was obtained the same as for figure 2.

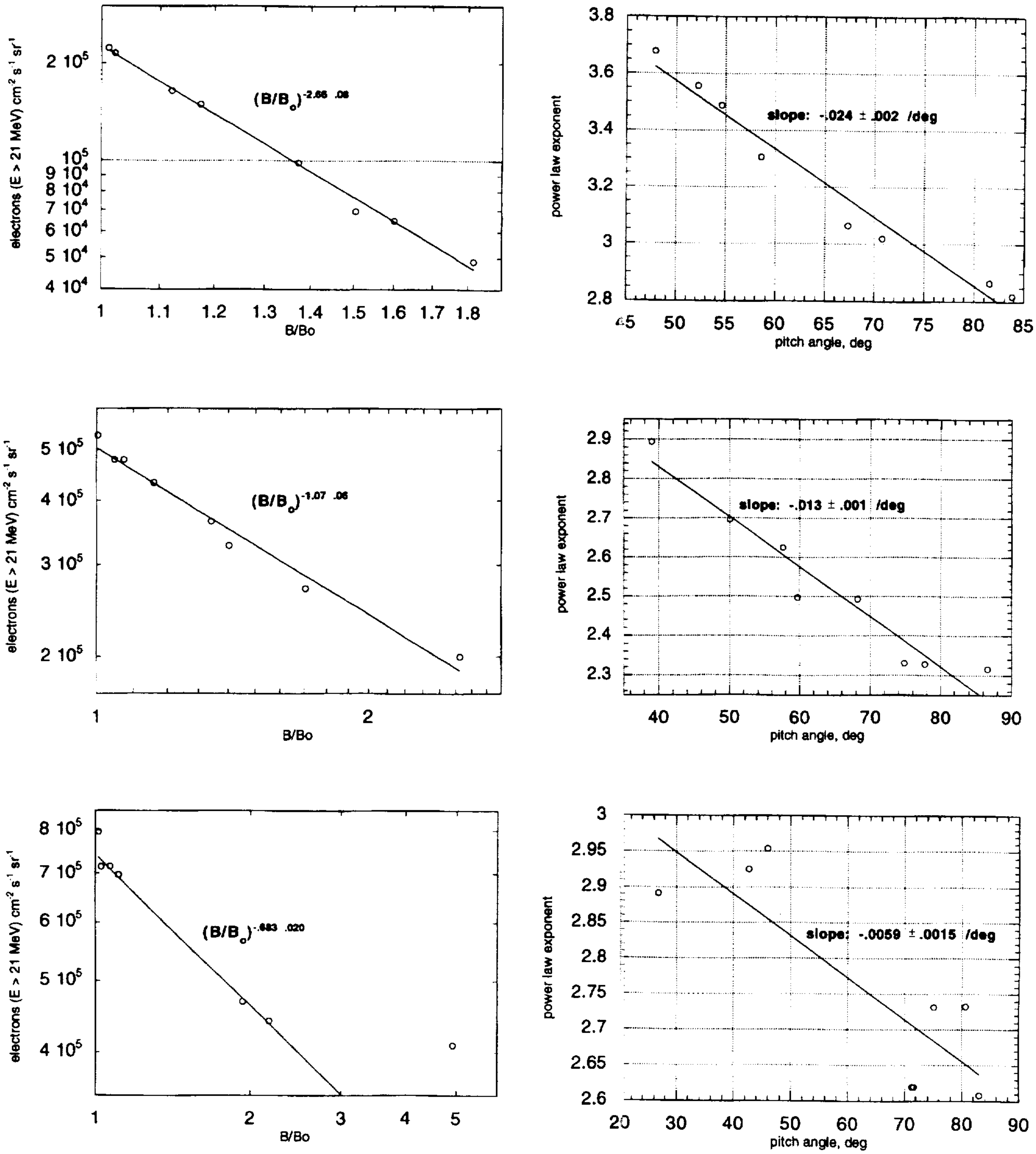

Figure 4. Electron pitch angle distributions and power law exponents for various pitch angles, for three locations along the Galileo Probe trajectory. The top data are for L = 1.44, the central plots for L = 1.8, and the bottom plots for L = 3.3. The pitch angle distributions become narrower as the planet is approached and the loss cone becomes larger. Power law exponents for electron pitch angle distributions are given on the plots. At L = 3.3 the highest and lowest points were omitted when the power law exponent was calculated. The spectral softening with decreasing pitch angle seems to become steeper, closer to Jupiter. Slopes from least-squares fits are given on the plots.

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